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SAR for Wearable Antennas with AMC Made using PDMS and Textiles

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Abstract

Besides the radiation and reflection performance of wearable antennas, arguably one of the most important parameters is their Specific Absorption Rate (SAR). This work aims to evaluate SAR for wearable antennas integrated with Artificial Magnetic Conductor (AMC) plane made using different material categories – textiles and a flexible polymer,. Two types of textiles, felt and ShieldIt Super are used to build the first, textile-based antenna, while polydimethylsiloxane (PDMS) and the fluidic metal eutectic gallium indium alloy (EGaIn) are used to build the second, polymer-based antenna. Both materials are chosen due to their flexibility conformity to the human body, thus providing comfort to users. Despite the SAR for both antenna types did not exceed the European regulatory limits of 2 W/kg averaged over 10g of tissues; there are considerable differences between them.

1. Introduction

Wireless Body Area Networks (WBAN) devices are foreseen to be capable of changing the human paradigm in applications in body sensing, medicine, health monitoring and emergency rescue [1]. The accessibility between the 2.4 GHz WBAN frequency and the widely used Industrial, Scientific, and Medical (ISM) (5.8 GHz) band [2] requires WBAN devices to be capable of operating in both frequencies using a single hardware. Besides that, a wearable system is envisioned to be conformal, lightweight, miniature in size, low profile, inexpensive, and easy to fabricate to ensure its attractiveness. This requires their components, including radiators to be made from special materials such as textiles and flexible polymers.

Another challenge for such antennas is to ensure that their radiations are not directed towards the human user by placing a reflective surface between the body and the antenna. However, to ensure that the antenna maintains a low profile characteristic, it is essential that the reflector is located as close as possible to the radiator. One of the structures which serves this purpose is metasurfaces such as artificial magnetic conductor (AMC) [3, 4, 5]. This is also to enable its safe operating condition for such wearable devices when operating on body, which is characterized by its Specific Absorption Rate (SAR). It is also known from [6] that these values obtained from commercial electromagnetic solvers such as CST Microwave Studio is closely correlated to measurements using commercial setups.

2. Materials and Antenna Design

The first antenna, which is a textile-based antenna, is built using two types of textiles: the conductive ShieldIt and the non-conductive felt. The felt substrate used is 3 mm thick, with a relative permittivity (ε_r) of 1.44, and loss tangent (tanδ) of 0.044. Meanwhile, ShieldIt Super is 0.17 mm thick with an estimated conductivity of 1.18 x 10^5 S/m. The overall structure for this textile based antenna consists of five layers, three layers of ShieldIt and two substrates based on [7]. It features a textile dipole placed on the top-most layer, followed by a 3 mm thick felt substrate. Next, a 3 x 3 AMC plane, which unit cells are formed using rectangular patches slotted with diamond shaped slots, is placed on the intermediate layer. This is followed by another 3 mm thick felt substrate layer before a full ground plane located at the bottom-most layer. The overall structure is sized at 90 x 90 x 6.51 mm^3.

On the other hand, a second polymer based antenna is built using two main material categories, the non-conductive polydimethylsiloxane and the conductive eutectic gallium indium alloy and copper plate as its conductors. Similarly, each PDMS substrate layer is also 3 mm thick, featuring a ε_r of 2.7, and a tanδ of 0.0134 [8]. Meanwhile, EGaIn is composed of 75.5% of Gallium and 24.5% of Indium resulting in an electrical resistivity of about 29.4 x 10^{-6} Ω-cm. This antenna cross section is similar to the textile-based antenna, except for an additional 1 mm thick layer on its top layer to keep the fluidic liquid embedded in the antenna. This is followed by a 3 mm PDMS substrate layer, with a 40 x 28 mm^2 EGaIn radiator embedded 1 mm into its thickness form the top. Next, another 3 mm thick PDMS substrate is placed underneath this layer. An AMC plane formed using 3 x 3 rectangular patches made from copper plates is embedded 1 mm into this second PDMS substrate.

Finally, a full ground plane formed using a 0.035 mm thick copper foil covers the bottom-most layer [5]. The overall size of this structure is 147 x 147 x 6.035 mm^3. Both designs were simulated using CST Microwvae Studio (MWS).

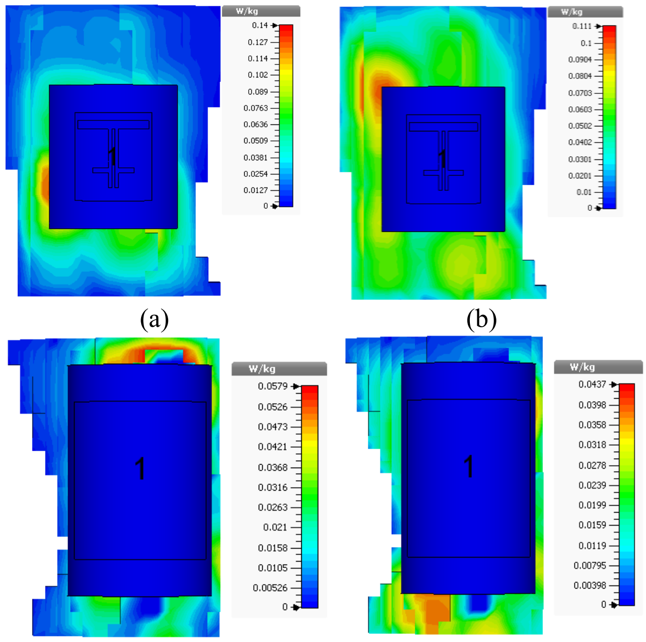
3. Results and Discussion

The AMC plane for the textile based antenna indicated a reflection phase bandwidth of 227 MHz (from 2.38 to 2.61 GHz) in the lower band and 831 MHz (from 5.26 to 6.1 GHz) in the upper band. Meanwhile, a smaller bandwidth is exhibited by the PDMS based AMC plane: 159 MHz (from 2.34 to 2.50 GHz) in the lower band and 596 MHz (5.61 to 6.16 GHz) in the upper band. For the overall radiator, the textile antenna in the planar state exhibited operation with a bandwidth of 162 MHz and 592 MHz in the 2.45 GHz and 5.8 GHz bands, respectively. Similarly, the planar PDMS antenna also operated from 2.39 to 2.48 GHz (in the lower band) and 5.62 to 5.90 GHz (in the upper band).

Table 1. Summary of the SAR averaged over 10 g of tissues for both antennas at two different frequencies and conditions.

Ant Condition	Freq (GHz)	SAR for PDMS Ant (W/kg)	SAR for Textile Ant (W/kg)
Bent at x-axis; r = 40mm	2.45	0.014	0.2
Bent at x-axis; r = 60 mm		0.032	0.15
Bent at y-axis; r = 40mm		0.043	0.14
Bent at y-axis; r = 60 mm		0.044	0.088
Bent at x-axis; r = 40mm	5.8	0.031	0.165
Bent at x-axis; r = 60 mm		0.023	0.97
Bent at y-axis; r = 40mm		0.043	0.11
Bent at y-axis; r = 60 mm		0.039	0.054

Prior to SAR assessments, the antennas were also bended at two axes (x- and y-axis) and two different radii (at r = 40 mm and 60 mm) to evaluate their performance when worn on body. Despite small changes, the antenna operation in both desired bands are maintained with reflection coefficients of lower than -10 dB. Due to this, common SAR evaluation frequencies are chosen at 2.45 GHz and 5.8 GHz to evaluate both antennas. The bent antennas at two axes and using two radii are placed 10 mm from the upper arm of a Hugo human body model available in CST, as seen in Figure 1. A summary of the result presented in Table 1 indicated that both antennas are capable of maintaining SAR levels of less than 2 W/kg as required by the European regulatory standards. It can be observed that the SAR values for the textile antenna are slightly lower at the higher 5.8 GHz compared to at 2.45 GHz, while similar values are observed for the PDMS antenna, except when bent at r = 40 mm at the x-axis.



(a) (b) (c) (d)

Figure 1. SAR distribution of antenna bent at the y-axis with: (a) textile antenna bent with r = 40 mm at 2.45 GHz; (b) textile antenna bent with r = 40 mm at 5.8 GHz; PDMS antenna bent with r = 40 mm at 2.45 GHz; and PDMS antenna bent with r = 40 mm at 5.8 GHz. [5, 7].

This may be attributed to the contribution of the AMC plane, which shielded the body from potential radiation. Besides that, the larger substrate size and consequently, the larger ground plane is also a contributor to the lower SAR seen in the PDMS antenna.

4. Conclusion

This work presents a SAR comparison between two antennas made using different materials. Both antennas featured a radiator, an AMC plane and a full ground plane. This AMC plane is then used as a reflector to reduce back radiation towards potential users when used in a wearable context, while maintaining a planar profile. The first textile-based antenna is built using felt as its substrate and ShieldIt conductive textile as its conductor. Meanwhile, the second polymer-based antenna is built using PDMS as its substrate, a metallic fluid, EGaIn, and copper plates as its conductors. Both antennas are compact in size and featured a dual-band operation. SAR assessments indicated a satisfactory safety level not exceeding the regulatory limit of 2 W/kg averaged over 10 g of tissues. The lower SAR levels for the PDMS based antenna is also due to its inherently larger ground plane caused by the substrate properties.

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